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WASTE WATER RECOVERY

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
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WASTE WATER RECOVERY

Office of Research and Development
Federal Water Pollution Control Administration

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Most of the U. S. population today utilizes raw water supplies containing water which has seen previous use for industrial or municipal purposes. It has been estimated that for the U. S. city experiencing only average re-use of its surface supply, one-half of its water has passed through a municipal or industrial outfall. For cities in the upper 10 per cent re-use bracket, their supplies have been used at least three times before. All use, therefore, is, in fact, re-use and, although the idea of waste water renovation may be a startling concept to the average citizen, the basic practice of water re-use is already widespread and will inevitably increase in the future, in this country and around the globe. In large part, of course, this re-use is not deliberate: it occurs from community to community as water flows downstream through surface or underground rivers. The quality of used water has been returned to tolerable, if not always satisfactory, levels through the application of various waste and water treatments, through dilution, and through "self-purification" in streams. Unfortunately, conventional water and waste treatment processes are ineffective, or only partially effective, against an expanding list of "refractory" compounds; dilution water is becoming, proportionately, less and less available, and stream self-purification generally does not work for inorganic stream pollutants and for organic compounds that have already resisted waste treatment.

Studies of present-day "completely" treated municipal waste effluents emphasize the fact that current treatment methods do not remove all soluble compounds present in the incoming waste stream. A survey of U. S. cities indicates that a single municipal use of water, even after both primary and secondary waste treatment, contributes an increment of roughly 50 mg/l. of resistant organic contaminants and perhaps 300-400 mg/l. of dissolved inorganic materials.[1] To alleviate

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[1] Tap waters may normally contain up to 400 or 500 mg/l of dissolved inorganics but only less than about 5 mg/l of organic matter. Hence, municipal use effectively doubles the inorganic concentration in water and increases organic concentration by a factor of 10.

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16. Abstracts Discussions by the Office of Research and Development, Federal Water Pollution Control Administration, of waste water recovery and the technology of advanced waste treatment are presented. Two general system configurations are described--series and parallel flow--and their costs estimated. Nine physical methods of water quality control techniques other than treatment are listed and their potential for water renovation and pollution control are evaluated.

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pollution caused by these refractory contaminants, new and improved methods of waste treatment will be required and a variety of these "advanced waste-treatment" processes are now under development. Moreover, since today's best conventional waste-treatment processes were not designed to remove nutrients, inorganic salts, or non-biologically degradable organics, it appears certain that improved waste water treatment will be based, to a large extent, on the addition of physical-chemical separation processes to the sequences currently employed. As the quality of waste effluents improves through the application of these improved treatment techniques, the effluent stream becomes of more and more value until it is literally "too good to throw away." At this point, water renovation has been accomplished--the treatment of waste water for pollution control and the simultaneous augmentation of water supply has been achieved. Here it is important to note that, as the need for improved pollution control increases, the fraction of the total waste water purification cost associated with "renovation for re-use" goes down.

The degree of purification required of a renovation process will be determined by the specific re-use purpose for which the water is intended. At a number of locations, irrigation water for non-edible crops, parks, golf courses, etc., is now being produced from conventionally-treated municipal waste effluents by chlorination without steps to remove organic or inorganic material. For broader irrigational application, advanced treatment might aim at removal of specific plant toxicants, e.g., boron, or at improved control of microbiological contaminants. For re-use as industrial water, selective removal of corrosive or scale-forming components might be the prime requirement. For recreational re-use, disinfection, removal of algae nutrients, and elimination of aesthetically objectionable qualities such as foaming and color might be sought. It appears inevitable, moreover, that renovation of waste water for deliberate municipal recycle will be essential in the future in a number of areas. For this purpose, renovation involving reduction of both organic and inorganic impurities and the production of optimum quality potable water is envisioned.

Examples of deliberate water re-use are increasing. At numerous communities in Texas, New Mexico, Arizona, Nevada, Utah, and California, municipal effluents are now being used for irrigation and for rough industrial purposes. In the East, a steel company has been using Baltimore's waste water for process purposes for over 20 years. During a severe drought in Kansas in 1957, the city of Chanute impounded its own waste water, treated it through its conventional water treatment process, and not only re-used it, but recycled it for a period of several months. At Whittier Narrows in Los Angeles County, 10 to 15 million gallons per day of municipal sewage is deliberately recovered and recharged to the ground water supply for municipal re-use. At Santee, California, highly purified municipal waste water is used in recreational lakes, without <u>any</u> dilution from natural water, for

boating, fishing, and even for swimming. Among other areas currently expressing interest in water re-use are Los Angeles, Lancaster, Richmond, and Orange County, California; Colorado Springs, and Aurora, Colorado; Tucson and Grand Canyon Park, Arizona; Dallas, Texas; East Chicago, Illinois; Montgomery County (Norristown), Pennsylvania; and both Nassau and Suffolk Counties on Long Island. In addition to interest here, there is serious consideration of the re-use concept in England, Belgium, South Africa, Japan, Mexico, the Bahamas, and Chile, along with a major, but completely unheralded water re-use project at Tel Aviv, Israel.

The need for the deliberate re-use of water is increasing as fresh water sources become exhausted or more remote and expensive. It is little realized, however, that re-use is inherent in the dual water supply and waste disposal use practiced along our water courses. Re-use, nonetheless, is very real and accounts for the fact that while 160 billion gallons of water per day are withdrawn for industrial and municipal use in the United States, only 6 to 8 billion gallons per day, or less than 5%, are not returned to a stream, lake, or the groundwater. This surprisingly small fraction of total water usage that is consumed points dramatically to the extent of water re-use now being experienced and the tremendous potential for extending our fresh-water resource through deliberate renovation practices.

Unfortunately, the actual gross impact of waste water renovation on our Nation's over-all water supply problem cannot be readily assessed because of the present unquantified natural re-use of our fresh water resource. Several specific examples can be cited, however: The Los Angeles County Sanitation Districts have prepared a "Plan For Water Re-Use" indicating that over 100 mg of municipal waste water could be recovered daily at nine locations in Los Angeles County. At Whittier Narrows alone where 10 to 15 mgd of sewage is now being recovered for ground water recharge and eventual re-use, it is estimated that over 50 mgd could be renovated. In another study it has been estimated that at least 900 mgd of New York City's 1200 mgd water use might be subject to recovery for re-use. Possibly a more satisfactory picture of the importance of water renovation, however, can be obtained by focusing attention on a simple generalized example. If a city or an industry were to renovate 80 per cent of the water it uses, its existing fresh water supply would be effectively enlarged five times! Clearly, a potential multiplication of our fresh water resource by a factor of this magnitude is of major importance.

Our long-range objective in research on water renovation is to provide the necessary treatment systems for attaining any degree of waste water purification which may be required at the minimum feasible cost. Significantly, the word "systems" is used. Rarely will an advanced waste-treatment process stand alone in the purification of waste water for re-use. Instead, systems of individual processes in series or in parallel will be required to meet particular needs.

Included in these systems must be one or more of a variety of "ultimate disposal" processes. These processes must provide for the permanent, non-pollutional disposal of the inevitable sludges and waste concentrates generated by the separation processes used. Disposal techniques may include incineration, digestion, or wet oxidation of organics; conveyance of various sludges and solid residues to the ocean or remote dump sites; or deep-well injection of brines into porous strata. Possible beneficial uses of waste concentrates as soil conditioners, fertilizers, or chemical raw materials are also included in the ultimate disposal category.

Two general system configurations can be used. In the series-type system (Figure 1), the total flow passes through all process in sequence. Each process contributes to quality improvement. In the example system pictured, conventional primary treatment removes material that readily settles or floats. The secondary biological step removes the readily biologically-degradable impurities and converts ammonia and organic nitrogen compounds to stable nitrate form. Coagulation-sedimentation, in the third position, eliminates suspended solids and colloids as well as most of the phosphorus present. Carbon adsorption removes residual dissolved organics. Electrodialysis returns the dissolved minerals level to an acceptable value. Finally, chlorination provides a positive disinfection step.

The same result can be obtained with a parallel-flow system (Figure 2). Here, primary and secondary treatment, coagulation-sedimentation, adsorption, and chlorination function as described above. In this case, however, demineralization is achieved by a "total removal" sequence, that is, evaporation plus distillate "polishing," which handles only about half of the total flow. Following this step, the completely purified water (the distillate) is blended with the stream from which all impurities except the salts have been removed.

It should be emphasized here that the concept of "blending" waters of high and low quality to produce water satisfactory for many purposes is of major economic significance--in fact, without it, total removal processes would probably not be "in the running" in water renovation research. It must be recognized that some waters are too pure to be used. Distilled water, for example, has a poor "taste" to most people, it is very corrosive to metal pipes and valves, and it is far too soft for acceptable use in washing. Such water, therefore, can be mixed with a hard water or with a water having excessive chlorides, for example, to produce a combined volume of nearly ideal quality water.

Because the cost of purifying water inevitably increases as the product quality increases, the production of a "too good" water is economically wasteful. Yet, some processes such as evaporation and

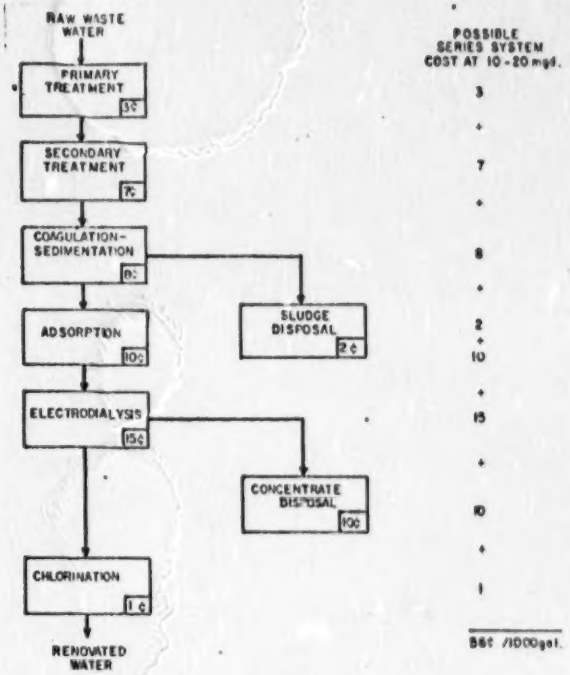

FIGURE 1 Generalized water renovation system, series flow.

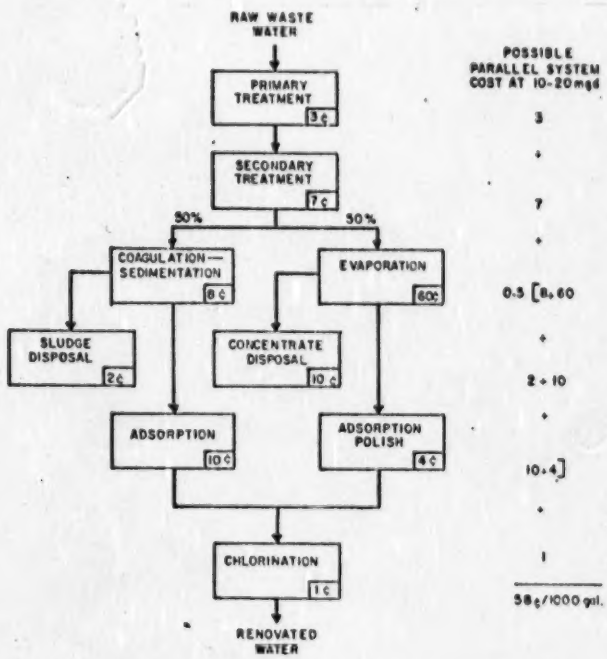

FIGURE 2 Generalized water renovation system, parallel flow.

reverse osmosis inherently produce these high-purity products. Cost reductions of 25-60% can be realized by blending these products with waters that may have excessive concentrations of dissolved salts but that have been treated (as by filtration plus adsorption or oxidation) for removal of organic impurities. Hence, processes that may "cost" as much as 50-70 cents per 1,000 gallons may actually contribute only 20-40 cents per 1,000 gallons to total system costs.

Application of this concept is fundamental to waste-water renovation systems and is of universal applicability because of the very low level of total contamination present in municipal waste waters. This blending technique cannot be fruitfully applied in the desalination of sea water because of the high concentration of dissolved solids in the sea. The principle can, however, be applied if desalination and water renovation are employed together. For example, the distillate from a sea-water evaporator could be blended with municipal waste water that had been purified of organics. Here, as in the case of waste water renovation, an important reduction in the cost of desalination (perhaps 40%) could be achieved.

Referring again to Figures 1 and 2, unit costs have been estimated for both a series-flow and a parallel-flow system at a scale of 10-20 mgd. First we see that the total system costs are so similar ($.56 vs. $.58/1,000 gallons) that neither system can, at this time, be dropped in favor of the other. Second, the cost of conventional and advanced treatment steps can be compared. In contrast to the present cost of $.10/1,000 gallons for primary-secondary treatment (Figure 1), coagulation-sedimentation, which very efficiently removes suspended and colloidal solids plus phosphates, is projected to cost an additional $.10/1,000 gallons. If the adsorption step were incorporated to eliminate BOD and persistent organics, the additional cost is raised to about $.20/1,000 gallons. The total water renovation cost would be, therefore, almost three times our present cost for waste treatment. To complete the renovation with electrodialysis might add another $.25/1,000 gallons to give a total renovation cost over five times the cost of existing waste treatment.

Clearly, this is not an illustration of "something for nothing." Yet, the cost picture is not really so dark. First, the renovation costs estimated are felt to be conservatively high and probably would not be exceeded under normal circumstances. Second, the actual costs should be reduced significantly as research and development programs bring us closer to optimum designs. Third, substitute processes now being investigated may reduce costs sizably. The powdered activated carbon process, for example, could conceivably replace, at half the cost, both coagulation-sedimentation and granular carbon adsorption.

Further, renovation costs are perhaps better and more fairly

compared with the combined costs of both conventional water supply and waste treatment, not with waste treatment costs alone--for both water pollution control and water supply augmentation are being accomplished by these systems. The sum of water supply and waste treatment costs, based on historical data and including source development, transmission, water treatment, and waste treatment (not including water distribution and waste collection) averages almost $.25/1,000 gallons in the U. S. and nearly $.30/1,000 gallons in prevailing high-cost areas in the country.

Finally, it must be remembered that 1) future costs for extending conventional waste treatment and for adding increments of water supply will undoubtedly be higher than those experienced today, that 2) economy-of-scale factors will help to reduce unit costs in larger installations, and that 3) the degree of waste water purification required (and, therefore, the cost) will depend on the re-use purpose intended (i.e., all waste water would certainly not have to be processed through the complete system shown).

Table I illustrates these latter two points by presenting a simplified summary, for one possible series-type renovation system, of the costs projected for producing effluents suitable for various types of re-use. This example system is the one which is furthest developed at present. A 75,000-gpd pilot plant of this configuration is now under study at our Lebanon, Ohio, field site. It is also this same basic system which was outlined to the Office of Science and Technology in August 1965 for application at New York City to augment the City's drought-throttled upland water supply. In this particular case, total capital cost for a 100-mgd water renovation system including delivery of product water back to the distribution system was estimated at $33 million with operating costs of 17¢/1,000 gallons. Other basic systems are, of course, possible including those which displace conventional primary and secondary treatment in part or even completely.

The technical feasibility of waste water renovation is essentially assured at this point through the success we have had with at least the one basic series-flow system described above. The primary challenge ahead relates to evaluation and development of alternative separation and disposal processes which show promise of improved performance or lower cost, optimization of process and system designs and operating conditions, confirmation of the reliability of performance of processes under continuous operation in the whole range of real field situations, refinement and confirmation of cost projections, establishment of more complete and more precise product water quality goals for various re-use applications, and development and optimization of water quality control techniques to minimize or modify the contaminants which become water-borne in the first place.

* Cost figures shown are based on the current stage of development of these processes and substantial reductions are expected as the R&D effort continues.

TABLE I

Re-use Applications and Costs for Example Water Renovation System

Treatment Sequence	Estimated Cumulative Capital Cost* 15 mgd million $	Estimated Cumulative Capital Cost* 100 mgd million $	Estimated Cumulative Operating Cost* 15 mgd ¢/1000 gal	Estimated Cumulative Operating Cost* 100 mgd ¢/1000 gal	Re-use applications
Raw waste water	0	0	0	0	None--highly polluting.
Primary Treatment	1	3	3	2	Partial pollution control --no direct re-use possible.
Secondary Treatment	2 1/2	9	10	6	Conventional pollution control; non-food crop irrigation.
Coagulation-Sedimentation	4	16	20	13	Improved pollution control; general irrigation supply; low quality industrial supply; recreational water supply; short-term water recharge.
Carbon Adsorption	6 1/2	25	30	19	Complete organic pollution control; high quality irrigation supply; good quality industrial supply; body-contact recreational supply; long-term ground water recharge.
Electrodialysis	10	41	55	34	Complete organic-inorganic pollution control; high quality industrial supply; indefinite ground water recharge.
Disinfection	11	42	56	35	Absolute pollution control; potable water supply.
Renovated water					

The last item above deserves further discussion because of its potential importance to both water renovation/advanced waste-treatment and water pollution control in general. By definition, "water quality control techniques" are those physical methods other than treatment which can be used to enhance water quality in the environment. These methods include:

1) Elimination--removal of a contaminant or its precursors from use.

2) Process Change--modification of the process in which a contaminant is used or created such that the contaminant is not released or its release is reduced.

3) Synthesis--deliberate introduction of properties into products which may eventually become water contaminants to reduce their pollutional effects or to enhance their removability.

4) Environmental Treatment--treatment of surface or ground water itself to remove pollutants or to diminish their effects.

5) Dispersion--distribution of a waste discharge over a larger area or into a larger volume of receiving water.

6) Detention--temporary hold-up of surge discharges for later gradual release or hold-up of portions of a discharge for release at a more advantageous time, e.g., at time of greater stream flow.

7) Diversion--transportation of a waste effluent to another location for discharge.

8) Dilution--artificial augmentation of natural stream flows to dilute wastes to acceptable concentrations.

9) Desensitization--shielding or immunization of a pollution receptor such that the effects of pollutants are eliminated or reduced.

The following is a preliminary analysis of the "potential" for each of the above techniques:

1) Elimination--Limited prospects exist for this method. Certain applications in industrial waste control exist, e.g., elimination of acid pickling and replacement of

it with mechanical cleaning, substitution of acid baths in plating operations for cyanide baths, or change of raw materials for certain processes to eliminate pollutant discharges. The possibilities should be explored but no widespread applicability is likely.

The complete elimination of water carriage waste disposal systems would also be included here. The transport of wastes in non-water diluted, highly concentrated bulk form to solid waste disposal facilities is a conceivable reality (the night soil system is still in use in much of Tokyo, for example, and pneumatic waste collection systems are technically feasible), but this approach would entail such drastic changes in waste handling and disposal concepts in the United States as to be extremely difficult on any broad scale, at least in existing cities.

The use of individual waste disposal appliances with no liquid discharge is a very unlikely eventuality. Because all "economy-of-scale" is lost, costs would be relatively high and, from a practical standpoint, the servicing requirements for such units to maintain assured, continuing operation (important because of both aesthetic and public health considerations) would present almost insuperable difficulties.

2) Process Change--As with Elimination, limited prospects for broad application exist. The replacement of water cooling with air cooling to alleviate thermal pollution and the "neutralization" of an acid waste by blending with a basic waste stream are examples. While this approach should be given full consideration where potentially applicable (essentially only in industry) and while research on these techniques should be greatly accelerated over the next few years, it seems clear that this is not an approach in which any single development offers promise of broad utility.

3) Synthesis--Many interesting possibilities under this category should be examined and seriously considered by the manufacturers and formulators of potential water polluting chemicals. The recent conversion of "hard" detergents to "soft," biodegradable detergents is, unquestionably, the best-known example of this approach and this general concept could well be extended as an important "design" criterion for a variety of new products. Biodegradability is not a universally

desirable property, however, (think of the lack of utility of a highly biodegradable termite-proofing compound), and other properties, some of which may actually increase the efficiency of use of the product, should also be considered. Treatability by other than biological mechanisms may be more appropos in the future, e.g., adsorbability or surface activity could be highly desirable properties for pesticides, herbicides, etc. Further, the formulation of improved "slow-release" fertilizers would both enhance their performance and reduce the nutrient content of run-off from agricultural areas.

It cannot be expected, however, that "non-polluting character" or "treatability" can be built into every material ultimately destined for the water environment. Performance by the product of its principal use function must take precedence over other desirable properties (a completely biodegradable detergent which wouldn't wash clothes or dishes, for example, would be absurd). In spite of this important limitation and a lack of over-all utility, and because of the potential usefulness of this approach for control of pollution from non-point sources which may otherwise be "uncontrollable," this general technique should be given major emphasis.

4) Environmental Treatment--The treatment of streams, lakes, and even underground waters to alleviate pollution is, basically, less efficient than treatment of discharges to these waters simply because of the larger volumes to be processed and the lower concentrations at which contaminants must be handled. Nevertheless, this technique may, in some instances, be the method of choice. The greatest advantage of this general method is its utility for all types of pollution, whether point source or non-point source in origin.

Examples of stream treatment include mechanical reaeration, mechanical destratification of natural lakes or impoundments, and the "harvesting" or "mining" of nutrients from eutrophying lakes. In most direct concept, a whole flowing river could be treated just as a waste effluent might be handled. As with Waste Treatment, ultimate disposal methods must also be developed and applied.

In addition to long-range continuing benefits such as preservation of water quality in impoundments, the potential solutions to special problems at certain locations

warrant a significant program of research in this area. The results could provide much needed "stopgap" emergency solutions to particular problems for which other solutions have not yet been developed. For example, it might be possible to greatly retard, if not even reverse, the eutrophication process in many lakes across the United States, including Lake Erie.

5) Dispersion--The pollutional effects of a waste discharge may conceivably be diminished by distributing the discharge into a somewhat larger volume of receiving water than might otherwise occur. This may be accomplished by multiple outfalls, by proper outfall location, by flow diverters, etc. While the technique has some utility, it is not capable of effecting major improvements in the Nation's over-all pollution problem and, therefore, will have relatively little impact in future technology.

6) Detention--This method does not include hold-up for purposes of treatment; rather this technique only serves to "disperse" the pollutional load from a point source over time (instead of over area as is accomplished with Dispersion). As with Dispersion, major improvements in the Nation's over-all pollution problem are not felt likely as a result of this technique.

7) Diversion--Diversion is as sure a method of pollution prevention in a given area as is Elimination or total pollution control by advanced waste-treatment. Certainly, if a waste discharge is conveyed to some other location, it will have zero polluting effect at the first location. The at-least partial fallacy here is that the discharge may exert its undesirable effects at the second location. These effects may, however, be tolerable or completely unimportant at the second location, in which case a positive benefit has been achieved.

The potential for complete pollution control from point sources by this method would seem to be quite high. Aside from cost competition with other control techniques (an obviously important factor affecting all methods listed), the arguments against Diversion are really only two: 1] a suitable diversion site may not be available, and 2] the water fraction of the waste stream would be "lost" to the location from which it is diverted and would not be available for any re-use in that area. These are two quite important factors, but it would appear that more consideration should be given to determining the

broad feasibility of this approach than has been to date. Incidentally, research requirements in this area should be relatively limited compared with those for other competitive pollution control methods such as waste treatment.

8) Dilution--Dilution, or low flow augmentation, is relatively broad in applicability and is potentially effective against all type of pollution, whether point or non-point in source or man-made or natural in origin. It is a corollary benefit to certain other water resource management goals and gains from this fact as well as in economic analyses where costs for construction of water impoundment structures may be charged aginst multiple purposes. At the same time, its functioning may be directly at odds with certain other water impoundment purposes, i.e., a flow augmentation reservoir should be kept nearly full, a flood control reservoir nearly empty.

Federal policy has already established that flow augmentation must only be employed to supplement other, more direct pollution control techniques. The technique is being widely used and more widely considered at present, perhaps because of our relative inability to control certain pollution effectively at the present stage of development of the other possible methods.

Dilution is not feasible when upstream impoundment sites are not present nor when natural average stream flows are insufficient. Nonetheless, Dilution represents an important, broadly applicable, and essentially "assured" control method which is effective even against presently impossible-to-control pollution from non-point sources. Research in this area, particularly on 1] effects of impoundment itself on water quality, and 2] on optimization of both design and operation of flow augmentation systems, should be highly productive and should receive increased emphasis.

9) Desensitization--This technique can only be though of as a "back-up" or "last-resort" method within our national policy of vigorous pollution abatement. The concept of "living with" pollution by making pollution receptors more resistant to or more tolerant of poor water quality would seem incompatible with current national goals. Yet, the concept itself <u>is</u> widely used and accepted in prevention of disease through immunization. While the approach is unconventional and even controversial

it deserves thorough and imaginative exporation before it is discarded.

In addition to the above nine caregories of water quality control techniques, there exist a variety of auxiliary procedures which are subject to technological investigation and development to improve pollution control or water renovation capabilities, either by enhancing performance or reducing cost. These include:

1) Complementary application of several different water quality control techniques (potentially all of them)--development of methods for application of systems analysis and economic optimization techniques 'n this context is highly important.

2) Water conservation--the use of a variety of water conservation techniques could lead to improved pollution control by providing smaller volumes of waste effluents at higher waste concentrations (examples o include staged countercurrent washing and rinsing methods in industry, recycle and re-use of in-plant process waters, and redesign of kitchen and bathroom fixtures and appliances to use less water).

3) Waste segregation--the segregation of waste streams into various type-categories may be advantageous.

4) "Collection" of non-point source wastes--practical means for accomplishing this goal would greatly extend over-all pollution control capability.

5) Blending--the concept of blending two streams to produce a product of intermediate quality has been previously discussed and is quite important in certain situations.

6) Conversion or dual use of existing facilities--existing capital investments must be considered in developing minimum cost solutions for specific problems. For example, existing conveyance facilities might be used, even on a part-time basis, to accomplish Diversion or ultimate disposal of waste concentrates. Also, the existing volume capacity of sewer lines themselves might be used in applying some new type of treatment.

7) Pre-concentration--following Waste Treatment or Environmental Treatment, disposal of the waste concentrates produced may be more economical if they are further concentrated by some auxiliary step.

8) Grouping--the potentially great savings through the "economy-of-scale" when treatment, control, or disposal facilities are designed to serve groups of communities and/or industries should be throughly examined. Included here is the concept (being emphasized in currently pending legislation) of encouraging industries to utilize municipal waste handling systems on a special fee basis to gain scale-economy for the industry and additional waste treatment revenue for the municipality.

9) Combination facilities--the deliberate combination of waste treatment operations with solid refuse disposal, water supply (including desalination where appropriate), and even power production should be given serious consideration.

General planning for an over-all research and development program by the Federal Water Pollution Control Administration has proceeded over the last 12-15 months in connection with the total water resources research planning being conducted by the Committee on Water Resources Research of the Office of Science and Technology. In accord with COWRR aims and because it is felt that a realistic R&D program achieving technically practicable and economically feasible results can be encompassed within the period, a ten-year target date for accomplishing the major part of our presently-definable research mission has been set. The projected cost of this over-all 10-year program is $475 million dollars of which approximately half applies directly to development of advanced waste-treatment and new ultimate disposal technology. Of this, the major expenditure will be required for pilot plants, field evaluation, and demonstration facilities. Table II indicates the breakdown by major research category.

While difficult to meaningfully simplify and generalize, it is believed that the minimum time to accomplish our 10-year goals with money as no object would be about four years. From this we project that with ten times the nominal 10-year budget, goals might be reached in five years; with five times the budget in six years; and with twice the budget in seven or eight years. On the other hand, with only half the planned 10-year budget, final goals might not be achieved for 20-25 years.

TABLE II

Ten-Year Budget Projection
Water Pollution Control Research

(millions of dollars)

COWRR Category		FY 1967*	FY 1968**	10-Year Total
V.A.	Identification of Pollutants	1.2	.9	29
V.B.	Sources and fate of pollution	1.0	1.7	27
V.C.	Effects of pollution	1.5	5.4	80
V.D.	Waste treatment processes	4.4	17.3	190
V.E.	Ultimate disposal of wastes	0.3	1.4	58
V.G.	Water quality control	0.3	2.4	79
VI.	Water resources planning	-	.6	8
VII.	Resources data	-	-	4
		8.7	29.7	475

* President's budget
** Proposed assuming new appropriations authorization

TECHNOLOGY OF ADVANCED WASTE-TREATMENT

Office of Research and Development
Federal Water Pollution Control Administration

September 1966

Historically, pollution control by "treatment" was the first active measure taken to supplement the inherent passive quality control mechanisms of "dilution" and "stream self-purification." Treatment is also, by far, the most popularly thought of method of pollution control and the one upon which more money has been spent, more attention directed, and more research conducted than any other. Even with this attention, it is still a fact that, at least in the municipal waste treatment area, the processes in use today are basically the same as those developed and put into practice some 50 years ago--this, in spite of the fact that water pollution and our understanding and appreciation of it have changed drastically, especially during the past decade. Bio-chemical Oxygen Demand (BOD) and coliform bacteria are no longer the only measures of waste discharged. Other types of materials are of growing concern: refractory organics, radionuclides, nutrients, viruses, inorganic salts, even heat. Pollutional effects of these materials may include accelerated eutrophication (over-fertilization), interference with water treatment or industrial use of the water, tainting of fish flesh, fish kills or other damage to stream biota, taste, odor, color, or foam in water supplies, and, potentially, even toxic or carcinogenic damage to man.

New concepts in waste treatment have been sadly lacking and only in the last few years has any concerted effort been directed to exploring "unconventional" approaches. Yet, it is a clear statement of fact that appropriate treatment would be able to restore the quality of a waste stream to <u>any</u> level desired and, in fact, could literally produce an effluent at least as good, if not better, than the original water supply. It is this promise that makes Waste Treatment the most important and potentially most fruitful area for "breakthrough" findings through intensified research and development. Physical-chemical separation principles, in particular, deserve much increased attention as supplements to and, conceivably, even substitutes for biological treatment methods. Quite intriguing is the possibility of applying variable treatment on a "demand" basis in order to achieve desired pollution abatement at much-reduced cost. This concept must be throughly explored, especially since such on-off or variable degree treatment is well possible with physical-chemical processes thus opening a new dimension in treatment plant operating methodology compared with that in today's biological plants. Our objective in advanced waste-treatment research is to develop the minimum cost systems of physical, chemical,

and biological treatment to achieve whatever degree of pollution control may be required in any specific situation.

In addition to the pollution control capabilities of treatment, we must recognize the potential effect of higher levels of treatment capabilities on our water supply problem. As better and better treatment is applied, at some point, the quality of a treated effluent will reach the point at which the water is "too good to throw away." This "renovated" water could then be directly reused for a number of purposes (agricultural, industrial, recreational, and even municipal), thereby augmenting our relatively dwindling fresh water resource.

Treatment for pollution control involves the performance of two different functions: 1] the separation of contaminants from the effluent stream, and 2] the disposal of the separated contaminants. Disposal cannot be accomplished by putting the contaminants back into the stream we are trying to protect--this would be folly, indeed. The disposal must, therefore, be non-pollutional and four possibilities are conceivable: 1] disposal by "dumping" into waste sinks such as special reservoirs, unused desert basins, or the ocean; 2] disposal to a sub-surface location, e.g., injection into deep porous strata or into underground cavities; 3] disposal by conversion to innocous form as by incineration, digestion, wet oxidation, etc.; and 4] disposal by utilization as a by-product. Each method or even combinations of methods may be applicable under different conditions at different locations.

The major weakness of the "treatment" approach is its inapplicability to non-point source discharges as, in order to impose waste treatment, the waste stream must pass through a confined flow system. Fortunately, essentially all municipal and industrial wastes are confined or confinable and even urban run-off is largely confined within storm or combined sewers (special problems will face us in attempting to develop treatment methods for storm flows).

With the development of really "complete" treatment techniques allowing recycle of renovated waste water for re-use and with suitable ultimate disposal methods for the waste concentrates developed, we will have attained, hopefully, the final answer to the control of pollution from municipal and industrial wastes. AWT techniques could conceivably allow the development of "dry" industries and municipal treatment plants from which absolutely no pollution would enter our surface or ground waters; AWT processes could completely change our present concepts of "adequate" waste treatment and could drastically reduce the otherwise necessary expenditure of multiple billions of dollars for provision of low flow augmentation (dilution) water to reduce pollution from presently untreatable wastes; AWT could allow continued economic growth and development in water-short areas of this country whose future

developable water supplies are presently limited; AWT could also postpone the time and reduce the total requirement for providing "new" fresh water to an area through importation or desalination. In short, a successful AWT technology, by renovating waste waters for deliberate reuse, would simultaneously alleviate two of our major water resource problems - water pollution and water supply.

AWT research follows the normal process development sequence from desk-top and laboratory exploratory studies through feasibility determinations at the bench to engineering studies in small pilot plants and to large pilot-scale process evaluation. The final process development step for any process will involve the design, construction and operation of a full-scale Field Evaluation Plant. The objective of the Field Evaluation Plant is to establish the performance and the cost of an advanced waste-treatment system on a scale of operation sufficiently great that potential municipal and industrial users of the system may select it with assurance. This type of assurance of performance and cost of new water pollution control technology will greatly expedite its introduction into practice and, in fact, must be obtained before any widespread municipal or industrial application of the technology can be expected.

To the present time, approximately 35 separation or ultimate disposal processes have been or are now being "screened" to assess their technical and economic feasibility. Of these, approximately 1/3 have been rejected from consideration for either technical or economic reasons while one process (granular activated carbon adsorption) has been brought well into large pilot plant process evaluation and is ready for full-scale field evaluation. Several others are now undergoing large-scale pilot-plant tests and large pilot plants for additional processes are now being designed or are under construction. Several more techniques are being studied in smaller pilot plants while others are, of course, still at laboratory scale. Table I presents a brief summary of AWT process development status. Table II presents the average composition of treated municipal waste effluents. At the initiation of research and development on advanced waste-treatment in late 1960, the capability of conventional "complete" municipal waste treatment was nominally as follows:

Table III

Removal Capability of Conventional Primary - Secondary Treatment

	Percent
BOD[1] removal	90
Total organic removal	80
Suspended solids removal	90
"Hard" detergent removal	50

[1]Biochemical oxygen demand

Table I

Summary of AWT Process Development Status

Process	Status	Current scale
Separation Processes--		
Adsorption-granular activated carbon	Process evaluation (ready for field evaluation)	300,000 gpd pilot plant in operation; 75,000 gpd pilot plant in operation
Adsorption-powdered activated carbon	Engineering studies	15,000 gpd pilot plant in operation
Adsorption-on inorganics	Rejected*	--
Adsorption-on coal	Rejected*	--
Adsorption-on polymers	Rejected*	--
Oxidation-by H_2O_2	Rejected*	--
Oxidation-by O_3	Feasibility studies	Bench-scale studies ready to start
Oxidation-by corona	Rejected*	--
Oxidation-by autoxidation	Exploratory studies	Laboratory tests underway
Electrodialysis	Process evaluation	75,000 gpd pilot plant in operation
Foam separation-simple	Process evaluation	500,000 gpd pilot plant in operation
Foam separation-with additives	Feasibility	Bench-scale studies ready to start
Emulsion separation	Rejected*	--
Electrolysis	Rejected*	--
Electrochemical degradation	Rejected*	--
Bio-denitrification	Process evaluation	200,000 gpd pilot plant being designed
Foam harvesting	Rejected*	--
Evaporation	Engineering studies	1,000 gpd pilot plant being constructed

Process	Status	Current scale
Extraction-of contaminants	Rejected*	--
Extraction-of water	Rejected*	--
Freezing	Feasibility	Initial bench-scale studies completed
Eutectic freezing	Rejected*	--
Hydration	Exploratory studies	Desk-top studies
Reverse osmosis	Engineering studies	5,000 gpd pilot plant in operation
Ion exchange	Feasibility studies	Bench-scale studies in progress
Coagulation-inorganic	Engineering studies (ready for process evaluation)	35,000 gpd pilot plant in operation 75,000 gpd pilot plant under construction 100,000 gpd pilot plant under construction[1] 200,000 gpd pilot plant being designed
Coagulation-organic polyelectrolytes	Feasibility studies (ready for engineering studies)	100,000 gpd pilot plant being designed[2]
Filtration-rapid sand and dual media	Feasibility studies	Bench-scale studies in progress
Filtration-diatomaceous earth	Engineering studies	75,000 gpd pilot plant in operation
Flotation	Engineering studies	35,000 gpd pilot plant in operation
Biomass treatment	Feasibility studies	Initial pilot-scale studies completed

[1] same equipment as 2
[2] same equipment as 1

Process	Status	Current scale
Activated sludge (control)	Process evaluation	100,000 gpd pilot plant being designed[3] 200,000 gpd pilot plant being designed[4]
Bio-nitrification	Process evaluation	200,000 gpd pilot plant being designed[5]
Biological PO_4 removal	Engineering studies	In-plant studies being planned 100,000 gpd pilot plant being designed[6]
Microscreening	Process evaluation	75,000 gpd pilot plant in operation
Combined chem-biological treatment	Feasibility studies	Bench-scale studies completed
Disposal Processes--		
Adsorbate incineration	Process evaluation (ready for field evaluation)	30" multiple hearth furnace in operation
Incineration	Engineering studies	Pilot plant being designed
Injection	Exploratory studies	Desk-top
Excavated cavities	Rejected *	--
Nuclear cavities	Exploratory studies	Desk-top
Pipelining	Feasibility studies	Bench-scale studies underway; Pilot-scale tests being planned
Wet oxidation	Exploratory studies	Desk-top
Ocean dumping	Exploratory studies	Desk-top
Sludge filtration	Feasibility studies	Laboratory studies underway; Bench-scale tests being planned

3 same equipment as 6
4 same equipment as 5
5 same equipment as 4
6 same equipment as 3

Process	Status	Current scale
Coagulant regeneration	Feasibility studies	Bench-scale studies being planned
By-product recovery	Exploratory studies	Desk-top
Foam recycle	Exploratory studies	Laboratory tests completed

* Rejected -- on basis of new information, "rejected" processes could be reconsidered.

Table II

Average Composition of Municipal Secondary Effluent

Component	Average concentration in secondary effluent (mg/l.)	Average increment added during water use** (mg/l.)	Average increment added during water use** (lb/day 1000 pop.)
Gross organics.....	55	52	64
Bio-degradable organics. (as BOD)	25	25	31
Methylene blue active substance (MBAS)*.....	6	6	7
Na^+.....	135	70	86
K^+.....	15	10	12
NH_4^+.....	20	20	25
Ca^{++}.....	60	15	18
Mg^{++}.....	25	7	9
Cl^-.....	130	75	92
NO_3^-.....	15	10	12
NO_2^-.....	1	1	1
HCO_3^-.....	300	100	120
CO_3^-	0	0	0
SO_4^-	100	30	37
SiO_3^-.....	50	15	18
PO_4^-	25	25	31
Hardness ($CaCO_3$).....	270	70	86
Alkalinity ($CaCO_3$).....	250	85	100
Total dissolved solids	730	320	390

* i.e., apparent alkyl benzene sulphonate.

** Concentration increase from tap water to secondary effluent.

	Percent
Total phosphate removal	30
Total nitrogen removal	50
Dissolved mineral removal	5

In comparison with the "complete" treatment of 1960, several tertiary processes already brought to pilot stage can give the following percent removals:

Table IV

Removal Capability of Several AWT Tertiary Processes

	Foam separation	Coagulation-sedimentation	Adsorption	Electro-dialysis
BOD removal	93	93	99	99
Total organic removal	85	85	99	99
Suspended solids removal	92	99	99	99
"Hard" detergent removal	85	55	95	98
Total phosphate removal	30	95	95	97
Total nitrogen removal	50	50	55	75
Dissolved mineral removal	5	10	15	50

At least for the immediate future, it appears most probable that, as in Table IV above AWT processes will be applied to the effluent from well-operated conventional primary-secondary treatment plants. At a later date, however, it is conceivable that today's conventional processes may be entirely displaced. Under proposed research, both approaches will be considered.

In the following paragraphs, a synopsis of the performance and projected cost of a number of the AWT processes studied is presented:

Coagulation-sedimentation--Alum or lime coagulation-sedimentation may be used to increase suspended solids removal efficiency in municipal waste water from the conventionally-attainable 90 percent to a 99 percent level and simultaneously to reduce effluent phosphate concentrations to 1 or 2 mg/l. Coagulation-sedimentation would generally not be considered as an "advanced" process in water treatment and industrial practice; however, it is included here as an "advanced" process because it is not conventionally applied to the treatment of municipal waste effluents and because the efficient removal of suspended and even colloidal solids

is a necessary pre-treatment for many of the other "Advanced" processes. Assuming a good quality secondary effluent, 50-100 mg/l. of alum or perhaps 200-300 mg/l. of lime are required to remove suspended and colloidal solids and phosphates. Standard water treatment flocculation tanks and sedimentation basins would be used.

The capital cost for this type of treatment will be less than $.10/daily gallon capacity for plants of the 10-20 mgd scale and about $.05/daily gallon capacity for 100 mgd plants. Operating costs, including capital amortization at 6 percent interest for 20 years, will be about $.08/1,000 gallons at 10-20 mgd and $.05/1,000 gallons at 100 mgd exclusive of sludge disposal.

Granular activated carbon adsorption--After removal of colloidal and suspended solids from sewage, soluble refractory and residual BOD organics may be very efficiently removed by contact with activated carbon granules. Such carbon will adsorb up to 20-30 percent of its own weight in mixed organics from waste water when used in counter-current flow fixed-bed contactors. At a mass velocity of 7 gal/min-ft^2 and a contact time of 40 minutes, more than 98 percent of both BOD and total organic matter can be removed. To minimize cost, the activated carbon can be regenerated and reused. Fortunately, the thermal regeneration of activated carbon following saturation with actual waste organics has been found possible. A series of 15 successive saturation-regeneration cycles have been performed with satisfactory regeneration efficiencies. This process is now being studied in a 300,000 gpd pilot plant at Pomona, California, under a joint research project of the Federal Water Pollution Control Administration and the Los Angeles County Sanitation Districts.

At a scale of 10-20 mgd, adsorption plant capital costs should be about $.15/daily gallon capacity and at 100 mgd, about $.09/daily gallon. Operating costs, including 20-year capital amortization at 6 percent interest, should be less than $.10/1,000 gallons for a 10-20 mgd plant and about $.06/1,000 gallons at the 100 mgd scale.

Electrodialysis--Except for dissolved inorganic salts added during use, a municipal waste water subjected to the foregoing treatment steps in series will have been restored to a chemical quality generally comparable to that before use. Inorganic

salts added during one pass through a municipal system will normally total about 300-400 mg/l. Since many water supplies contain these same dissolved salts at approximately this concentration, one municipal use of water generally doubles the salt content. Fortuitously, a single-pass electrodialysis reduces the concentration of dissolved inorganic solids by 40-50 percent, just the percentage required to remove the increment of mineral pollutants added during use. Extended bench-scale tests and current pilot-scale studies at 75,000 gpd have established that the power requirements for this service are only 6-10 kwh/1,000 gallons. For "typical" waste waters, polarization can be avoided if a current density-to-concentration ratio of 750 $(ma/cm^2)/(g.eq./l.)$ is not exceeded. Under these conditions, effective cell-pair area requirements are less than 0.004 ft^2/gpd and concentration ratios greater than 10:1 can be achieved with proper pH control; ratios of 50:1 have even been attained. The feed must be carefully pretreated to operated electrodialysis stacks in this service successfully. With suspended solids removed to avoid plugging and with dissolved and colloidal organics removed to avoid membrane fouling, electrodialysis of waste water is relatively straightforward although very recent results may indicate some complications from microbiological forms.

Capital costs for electrodialysis equipment should be less than $.15/daily gallon capacity at 10-20 mgd and under $.11/daily gallon capacity at 100 mgd. Unless serious unforeseen difficulties are encountered in pilot-scale tests, total operating costs should not exceed $.15/1,000 gallons at 10-20 mgd and should be about $.10/1,000 gallons at 100 mgd.

Foam separation--Prior to the decision by United States soap and detergent manufacturers to shift from "hard" (ABS) to "soft" (LAS) surfactants, considerable work on the foam separation process was accomplished. With the switch-over in formulation, our effort has been cut back but, nonetheless, still maintained at a low level because of the very low cost associated with the process, the removals of both surface active and, apparently, non-surface active organics from sewage which can be achieved, the potential application to certain industrial wastes, and the possible use of certain additives which might enhance process performance appreciably. In foam separation, the built-in foaming tendency of waste waters is utilized to achieve removal of gross organic impurities. This is done by deliberately generating a foam and then removing the foam and its associated contaminants from the system. The removal mechanisms involved are surface

. . . adsorption for the soluble components and flotation for the suspended materials. The most efficient removals are those relating to surfactants. For example, 80 to 90 percent removal of ABS from municipal secondary effluent to residual concentrations of 0.5-1.0 mg/l. is routinely achieved at the laboratory scale. Moreover, 25-40 percent of the gross organic material in secondary effluents is also concentrated into the foam (at least this was the case prior to introduction of LAS).

A 0.5 mgd pilot plant for developing improved design and operating standards for full-scale foam separation has been constructed and a testing program is underway. Optimum results are generally obtained at aeration rates corresponding to gas-to-liquid volume ratios of approximately 5 : 1 and with liquid residence times of about 5 minutes. The depth of liquid is important and a minimum depth of five to six feet appears desirable. A height of foam of about two feet above the liquid is necessary to avoid excessive volumes of collapsed foam.

For foaming plants of 10-20 mgd capacity, capital costs should be roughly 3 cents per daily gallon capacity and operating costs (at 6 percent interest on capital investment for 20 year amortization) will be between 1 and 2 cents per 1,000 gallons. At 100 mgd, costs would be roughly half of these.

Powdered activated carbon adsorption--This adsorption process gives much higher adsorption rates and even higher product quality than with granular carbon. Problems under study are in separation of the carbon after contact and in reactivation. No pre-filtration is required but post-filtration may be needed. Cost may be under that for the granular carbon process and lack of pre-treatment requirements gives a further potential advantage. A 15,000 gpd pilot plant is now in operation.

Reverse Osmosis--The application of pressures in excess of osmotic pressure can drive fresh water through a semi-permeable membrane out of waste water as well as out of sea or brackish water. Small-scale tests with effluent from a municipal trickling filter have produced products of less than 50 mg/l. TDS and less than 5 mg/l. organics at flux rates of 10-20 gal/ft^2 per day. Product volumes up to 85-90 percent of the feed were obtained in these runs. The preliminary experiments conducted to date have each lasted only a matter of hours; however, the length of time over which satisfactory flux rates

can be maintained, membrane life, corrosion rates, biological effects on membranes, etc., are all unknown factors at this time. To learn the extent of these problems and to develop answers to them, studies on a 5,000-gpd reverse osmosis pilot plant are just being initiated. Meaningful costs for this process cannot be estimated at this date.

Biological phosphate removal--Recently it has been discovered that, at least in certain circumstances, rather high efficiency removal (~80-90%) of phosphates from municipal sewage may be achieved by modification of design and operating variables of the activated sludge process. The mechanisms of this removal are presently unknown but indicator variables appear to be: mixed liquor suspended solids concentration in the aeration basins, aeration rate, solids detention time in the final clarifier, and method of sludge wasting. Accelerated effort is currently being applied to this process; appropriately selected conditions are to be imposed on a full-scale (~1 mgd) plant as a crucial test of the concept and both small and large (100,000 gpd) pilot plants are being designed and constructed. Firm cost projections are not available but capital costs for plant modifications probably should not exceed 4-5¢/daily gallon and incremental operating costs should be less than 3¢/1,000 gallons for conversion of 10-20 mgd activated sludge plants to this process.

Nitrification-denitrification--The conversion of ammonia and organic nitrogen compounds to nitrates by biological oxidation can be reasonably well and reliably controlled at present. Laboratory and small pilot-scale tests have shown that biological denitrification back to nitrogen gas is also possible. The biologic reduction is performed by specially acclimated microorganisms which are maintained in a sludge recycle system similar in physical appearance to the activated sludge process. Rather good efficiencies of nitrogen removal (approximately 80%) have been achieved and a 200,000 gpd pilot plant is now being designed. Preliminary estimates of costs above conventional secondary treatment for construction of this type plant are 3-4¢/daily gallon for 10-20 mgd plants and 1¢/1,000 gallons for operation.

Evaporation--Experimental work on evaporation of waste water for water renovation purposes is in an early stage. Desk-top analyses and certain key experiments have already been conducted, however. From these studies it has been

established that volatile contaminants carry over into the distillate in quantities quite sufficient to impair product quality. While the total organic content of the distillate from an atmospheric pressure evaporation of secondary effluent may be only 1-2 mg/l., nonetheless, substantial odor is present. Fortunately, it appears that the odor may be effectively removed by activated carbon. Practically all the ammonia in the feed appears in the distillate and would unquestionably have to be removed to provide water of potable quality. Ammonia will also introduce corrosion problems and may dictate against construction in cupro-alloy. Calcium carbonate scaling can apparently be prevented by pH control. Dissolved, colloidal, or suspended organics do not seem to interact with this scale so as to complicate carbonate scale control in any way. Calcium sulphate or calcium phosphate scale problems have not been defined as yet but could, of course, cause appreciable difficulty.

Assuming that no major unforeseen obstacles arise during planned pilot-scale evaporation studies, distillation of municipal waste waters would have the following operating advantages as compared with seawater distillation:

(a) lower boiling point elevation,
(b) lower volumes of feed and of blow-down per unit of product water, and
(c) higher top temperatures.

To allow for unexpected difficulties and other contingencies, it appears best, in spite of these probable operating advantages, to predict that costs of waste water evaporation will be about the same as those for sea-water evaporation, that is, around 55-65¢/1,000 gallons at the 10-20 mgd scale. Firm cost projections must await larger-scale investigations.

Chemical oxidation--The oxidative destruction of organic molecules in dilute aqueous solution is a theoretical means for "polishing" waters to very low residual organic contents. It has been shown that active-oxygen oxidants, e.g., hydroxyl free radicals from H_2O_2 or ozone, will attack soluble organic molecules in general, yielding a variety of oxidized products including substantial quantities of carbon dioxide.

Oxidation of all organics present in waste water has not been achieved, but reductions of 50-70% chemical oxygen demand (COD) have been routinely accomplished. ABS,

incidentally, is quite readily oxidized and removals of 98% down to 0.1-0.2 mg/l. are achieved.

Based on the present state of our information on the oxidation process and current costs of oxidants, it does not appear that oxidation can be economically competitive with activated carbon adsorption for removal of the bulk of organic pollutants in biologically treated waste effluents. Nevertheless, oxidation may have some effective role as a "polishing" agent in final removal of residual organics from wastes.

In conclusion, one more point should be stressed concerning the need for and the promise of AWT research. Perhaps the most important concept to grasp in this area is the relationship between increases in waste treatment efficiency and reductions in the pollution load discharged to our streams. An increase in BOD removal from 90% to 95%, for example, would cut the BOD discharge in half; an increase to 99% would reduce the pollution load discharged by a factor of 10!